

1 USING AN EXTERNAL SPIRAL SERVO WRITER TO WRITE REFERENCE SERVO

2 SECTORS AND SPIRAL TRACKS TO A DISK TO FACILITATE WRITING

3 PRODUCT SERVO SECTORS TO THE DISK

5 BACKGROUND OF THE INVENTION

6 Field of the Invention

7 The present invention relates to disk drives for computer systems. More particularly, the
8 present invention relates to using an external spiral servo writer to write reference servo sectors
9 and spiral tracks to a disk to facilitate writing product servo sectors to the disk.

10 Description of the Prior Art

When manufacturing a disk drive, product servo sectors 2₀-2₇ are written to a disk 4 which define a plurality of radially-spaced, concentric data tracks 6 as shown in the prior art disk format of FIG. 1. Each product servo sector (e.g., servo sector 2₄) comprises a preamble 8 for synchronizing gain control and timing recovery, a sync mark 10 for synchronizing to a data field 12 comprising coarse head positioning information such as a track number, and servo bursts 14 which provide fine head positioning information. During normal operation the servo bursts 14 are processed by the disk drive in order to maintain a head over a centerline of a target track 16 while writing or reading data. In the past, external servo writers have been used to write the product servo sectors 2₀-2₇ to the disk surface during manufacturing. External servo writers 18 employ extremely accurate head positioning mechanics, such as a laser interferometer, to ensure 20 the product servo sectors 2₀-2₇ are written at the proper radial location from the outer diameter of 22 the disk to the inner diameter of the disk. However, external servo writers are expensive and 24 require a clean room environment so that a head positioning pin can be inserted into the head disk assembly (HDA) without contaminating the disk. Thus, external servo writers have become 25 an expensive bottleneck in the disk drive manufacturing process.

26 The prior art has suggested various “self-servo” writing methods wherein the internal
27 electronics of the disk drive are used to write the product servo sectors independent of an

1 external servo writer. For example, U.S. Patent No. 5,668,679 teaches a disk drive which
2 performs a self-servo writing operation by writing a plurality of spiral tracks to the disk which
3 are then processed to write the product servo sectors along a circular path. The spiral tracks are
4 written “open loop” by seeking the head from an outer diameter of the disk to an inner diameter
5 of the disk. The disk drive calibrates acceleration/deceleration impulses to seek the head from
6 the outer to inner diameter in a desired amount of time. Accurate radial positioning of the spiral
7 tracks assumes the calibration process is accurate and that the calibrated acceleration/deceleration
8 impulses will generate a repeatable response over multiple seeks. However, the calibration
9 process will inevitably exhibit some degree of error and the dynamics of the disk drive will
10 change between seeks inducing errors in the radial position of the spiral tracks. Dynamic errors
11 which degrade the spiral tracks written during an open loop seek include vibration of the HDA,
12 flutter and non-repeatable run-out of the disk and spindle bearings, stiction and non-repeatable
13 run-out of the pivot bearings, windage on the head and arm, and flex circuit bias, windage and
14 vibration. Errors in writing the spiral tracks will propagate to the product servo sectors, thereby
15 degrading the operating performance of the disk drive and reducing the manufacturing yield.

16 In the ‘679 patent, each spiral track is written to the disk as a high frequency signal (with
17 missing bits), wherein the position error signal (PES) for tracking is generated relative to time
18 shifts in the detected location of the spiral tracks. In addition, the ‘679 patent generates a servo
19 write clock by synchronizing a phase-locked loop (PLL) to the missing bits in the spiral tracks.
20 In order to initially synchronize the PLL to the missing bits the head must servo accurately in a
21 circular path since PLL phase error can occur due to actual timing errors or radial tracking errors.
22 Conversely, PLL phase errors cause radial tracking errors making it difficult to simultaneously
23 maintain the head in a circular path by servoing on the spiral tracks while attempting to
24 synchronize the PLL to the missing bits.

25 There is, therefore, a need to improve the servo writing process for a disk drive by
26 reducing the bottleneck and expense of external servo writers while maintaining adequate
27 operating performance and manufacturing yield.

1 **SUMMARY OF THE INVENTION**

2 The present invention may be regarded as a method of writing product servo sectors to a
3 disk of a disk drive. The disk drive comprises control circuitry and a head disk assembly (HDA)
4 comprising the disk, an actuator arm, a head connected to a distal end of the actuator arm, and a
5 voice coil motor for rotating the actuator arm about a pivot to position the head radially over the
6 disk. A head positioning pin of an external spiral servo writer is inserted into the HDA, wherein
7 the head positioning pin for engaging the actuator arm. The external spiral servo writer derives a
8 radial location of the head and actuates the head positioning pin in response to the radial location
9 of the head in a closed loop system to rotate the actuator arm about the pivot in order to position
10 the head radially over the disk. The external spiral servo writer then writes a plurality of
11 reference servo sectors in a substantially circular reference path, each reference servo sector
12 comprising a sync mark and a plurality of servo bursts. The external spiral servo writer also
13 writes a plurality of spiral tracks, wherein each spiral track comprises a high frequency signal
14 interrupted at a predetermined interval by a sync mark. The head positioning pin is then removed
15 from the HDA. The servo bursts in the reference servo sectors are then read using the head
16 internal to the disk drive to generate a position error signal used to maintain the head along the
17 circular reference path while reading the sync marks in the reference servo sectors to generate a
18 reference sync mark detect signal. A servo write clock is synchronized in response to the
19 reference sync mark detect signal. Product servo sectors are then written to the disk to define a
20 plurality of radially spaced, concentric data tracks. The high frequency signal in the spiral tracks
21 is read using the head internal to the disk drive to generate a position error signal used to
22 maintain the head along a substantially circular target path while reading the sync marks in the
23 spiral tracks to generate a spiral sync mark detect signal. Synchronization of the servo write
24 clock is maintained in response to the spiral sync mark detect signal. The servo write clock and
25 the head internal to the disk drive are used to write the product servo sectors along the circular
26 target path.

1 In one embodiment, each reference servo sector comprises a preamble, wherein a read
2 clock is synchronized to the preamble and then used to read the sync marks from the reference
3 servo sectors.

4 In another embodiment, the synchronization of the servo write clock is maintained in
5 response to the high frequency signal in the spiral tracks. In one embodiment, the head internal
6 to the disk drive is used to read the high frequency signal in the spiral tracks to generate a read
7 signal, and the servo write clock is used to sample the read signal to generate a sequence of
8 sample values. A timing recovery measurement is generated in response to the sample values,
9 and synchronization of the servo write clock is maintained in response to the timing recovery
10 measurement. In one embodiment, a coarse timing recovery measurement is generated in
11 response to the sync mark detect signal, and a fine timing recovery measurement is generated in
12 response to the high frequency signal in the spiral tracks. In one embodiment, a modulo-N
13 counter is clocked by the servo write clock, and the coarse timing recovery measurement is
14 generated in response to the modulo-N counter. In one embodiment, the modulo-N counter is
15 initialized in response to the reference sync mark detect signal.

16 In yet another embodiment, each reference servo sector comprises a preamble wherein a
17 read clock is synchronized to the preamble and then used to synchronously demodulate the sync
18 mark and servo bursts in the reference servo sector. The servo write clock is then used to
19 synchronously demodulate the sync mark and the high frequency signal between the sync marks
20 in the spiral tracks without synchronizing the write clock to a preamble.

21 In one embodiment, the control circuitry within the disk drive is used to read the sync
22 marks in the reference servo sectors and the spiral tracks in order to synchronize the servo write
23 clock. In an alternative embodiment, an external product servo writer is used to read the sync
24 marks in the reference servo sectors and the spiral tracks in order to synchronize the servo write
25 clock.

26 The present invention may also be regarded as a disk drive comprising control circuitry
27 and a head disk assembly (HDA) comprising a disk, an actuator arm, a head connected to a distal

1 end of the actuator arm, and a voice coil motor for rotating the actuator arm about a pivot to
2 position the head radially over the disk. The disk comprises a plurality of reference servo sectors
3 in a substantially circular reference path, each reference servo sector comprising a sync mark and
4 a plurality of servo bursts, the servo bursts for maintaining the head along the circular reference
5 path while reading the sync marks in the reference servo sectors to generate a reference sync
6 mark detect signal for use in synchronizing a servo write clock. The disk further comprises a
7 plurality of spiral tracks, each spiral track comprising a high frequency signal interrupted at a
8 predetermined interval by a sync mark, the high frequency signal for maintaining the head along
9 a circular target path while reading the sync marks in the spiral tracks to generate a spiral sync
10 mark detect signal for use in maintaining synchronization of the servo write clock. The disk
11 further comprises a plurality of product servo sectors written using the servo write clock, the
12 product servo sectors defining a plurality of radially spaced, concentric data tracks.

13 **BRIEF DESCRIPTION OF THE DRAWINGS**

14 FIG. 1 shows a prior art disk format comprising a plurality of radially spaced, concentric
15 tracks defined by a plurality of product servo sectors.

16 FIG. 2A and 2B illustrate an embodiment of the present invention wherein an external
17 spiral servo writer is used to write a plurality of reference servo sectors and a plurality of spiral
18 tracks to the disk for use in writing product servo sectors to the disk.

19 FIG. 3A shows an embodiment of the present invention wherein a servo write clock is
20 synchronized by clocking a modulo-N counter so that it reaches terminal count at the frequency
21 of sync marks in the reference servo sectors.

22 FIG. 3B shows an eye pattern generated by reading the spiral track, including the sync
23 marks in the spiral track.

24 FIG. 4 illustrates an embodiment of the present invention wherein synchronization of the
25 servo write clock is maintained from a coarse timing recovery measurement generated in
26 response to the sync marks recorded in the spiral tracks and a fine timing recovery measurement
27 generated in response to the high frequency signal in the spiral tracks.

1 FIGs. 5A-5B illustrate how in one embodiment the control circuitry for demodulating the
2 servo bursts in product servo sectors is also used to demodulate the high frequency signal in the
3 spiral tracks as servo bursts to generate the PES for tracking.

4 FIGs. 6A-6B show an embodiment of the present invention for calibrating the correlation
5 between the PES generated from reading the spiral tracks and off-track displacement.

6 FIG. 7 shows an embodiment of the present invention wherein an external product servo
7 writer is used to process the spiral tracks in order to write the product servo sectors to the disk.

8 FIG. 8 shows an embodiment of the present invention wherein an external spiral servo
9 writer is used to write the reference servo sectors and the spiral tracks, and a plurality of external
10 product servo writers write the product servo sectors for the HDAs output by the external spiral
11 servo writer.

12 FIG. 9 shows an embodiment of the present invention wherein an external spiral servo
13 writer is used to write the reference servo sectors and the spiral tracks, and the control circuitry
14 within each product disk drive is used to write the product servo sectors.

15 **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

16 FIG. 2A and 2B illustrate an embodiment of the present invention for writing product
17 servo sectors to a disk 16 of a disk drive 18. The disk drive 18 comprises control circuitry 20 and
18 a head disk assembly (HDA) 22 comprising the disk 16, an actuator arm 24, a head 26 connected
19 to a distal end of the actuator arm 24, and a voice coil motor 28 for rotating the actuator arm 24
20 about a pivot to position the head 26 radially over the disk 16. A head positioning pin 30 of an
21 external spiral servo writer 32 is inserted into the HDA 22, wherein the head positioning pin 30
22 for engaging the actuator arm 24. The external spiral servo writer 32 derives a radial location of
23 the head 26 and actuates the head positioning pin 30 in response to the radial location of the head
24 26 in a closed loop system to rotate the actuator arm about the pivot in order to position the head
25 radially over the disk 16.

26 The external spiral servo writer 32 writes a plurality of reference servo sectors 34 in a
27 substantially circular reference path, each reference servo sector 34 comprising a sync mark 10

1 and a plurality of servo bursts 14 (FIG. 1). The external spiral servo writer 32 also writes a
2 plurality of spiral tracks 36₀-36_N, wherein each spiral track comprises a high frequency signal
3 interrupted at a predetermined interval by a sync mark. The head positioning pin 30 is then
4 removed from the HDA 22. The servo bursts 14 in the reference servo sectors 34 are then read
5 using the head 26 internal to the disk drive 18 to generate a position error signal used to maintain
6 the head 26 along the circular reference path while reading the sync marks 10 in the reference
7 servo sectors 34 to generate a reference sync mark detect signal.

8 A servo write clock is synchronized in response to the reference sync mark detect signal.
9 Product servo sectors are then written to the disk 16 to define a plurality of radially spaced,
10 concentric data tracks. The high frequency signal 38 in the spiral tracks 36₀-36_N is read using the
11 head 26 internal to the disk drive 18 to generate a position error signal used to maintain the head
12 26 along a substantially circular target path while reading the sync marks 40 in the spiral tracks
13 36₀-36_N to generate a spiral sync mark detect signal. Synchronization of the servo write clock is
14 maintained in response to the spiral sync mark detect signal. The servo write clock and the head
15 26 internal to the disk drive 18 are used to write the product servo sectors along the circular
16 target path.

17 In the embodiment of FIG. 2A, the external spiral servo writer 32 comprises a head
18 positioner 42 for actuating the head positioning pin 30 using sensitive positioning circuitry, such
19 as a laser interferometer. Pattern circuitry 44 generates the data sequence written to the disk 16
20 for the reference servo sectors 34 and the spiral tracks 36₀-36_N. The external spiral servo writer
21 32 writes a clock track 46 (FIG. 2B) at an outer diameter of the disk 16, and a clock head 48 is
22 inserted into the HDA 22 for reading the clock track 46 to generate a clock signal 50. Timing
23 circuitry 52 in the external spiral servo writer 32 processes the clock signal 50 to enable the
24 pattern circuitry 44 at the appropriate time so that the reference servo sectors 34 and spiral tracks
25 36₀-36_N are written at the appropriate circumferential location. The clock signal 50 also enables
26 the pattern circuitry 44 to write the sync marks 40 (FIG. 3B) within the spiral tracks 36₀-36_N at
27 the same circumferential location from the outer diameter to the inner diameter of the disk 16.

1 As described below with reference to FIG. 4, the constant interval between sync marks 40
2 (independent of the radial location of the head 26) enables the servo write clock to maintain
3 synchronization.

4 In the embodiment of FIG. 2A, the entire disk drive 18 is shown as being inserted into the
5 external spiral servo writer 32. In an alternative embodiment, only the HDA 22 is inserted into
6 the external spiral servo writer 32.

7 After the external spiral servo writer 32 writes the reference servo sectors 34 and the
8 spiral tracks 36₀-36_N to the disk 16, the head positioning pin 30 and clock head 48 are removed
9 from the HDA 22 and the product servo sectors are written to the disk 16. In one embodiment,
10 the control circuitry 20 within the disk drive 18 is used to process the reference servo sectors 34
11 and spiral tracks 36₀-36_N in order to write the product servo sectors to the disk 16. In an
12 alternative embodiment described below with reference to FIGs. 7 and 8, an external product
13 servo writer is used to process the reference servo sectors 34 and spiral tracks 36₀-36_N in order to
14 write the product servo sectors to the disk 16 during a “fill operation”.

15 At the beginning of the fill operation, the reference servo sectors 34 are processed in
16 order to synchronize the servo write clock. The reference servo sectors 34 are processed similar
17 to conventional product servo sectors. The circumferential location of the reference servo sectors
18 34 is first determined by searching for the sync mark 10 asynchronously. Once a sync mark 10 is
19 detected, the reference servo sectors 34 are detected synchronously by synchronizing a read clock
20 to the preamble 8 (FIG. 1) preceding the sync mark 10. The servo bursts 14 in the reference
21 servo sectors 34 are also demodulated in a conventional manner to generate a position error
22 signal (PES) for use in maintaining (tracking) the head 26 along a circumferential path while
23 reading the reference servo sectors 34. In one embodiment, several tracks of reference servo
24 sectors 34 are written to the disk 16 to facilitate finding and tracking the reference servo sectors
25 34.

26 FIG. 3A shows an embodiment of the present invention wherein two spiral tracks are
27 written between each reference servo sector (e.g., spiral tracks 36₀ and 36₁ written between

1 reference servo sectors 34₀ and 34₁). Also shown in FIG. 3A is a saw-tooth waveform 54
2 representing the value of a modulo-N counter. The modulo-N counter is clocked by the servo
3 write clock, and the frequency of the servo write clock is adjusted until the modulo-N counter
4 reaches terminal count synchronous with detecting the sync mark 10 in the reference servo sector
5 34. The servo write clock may be generated using any suitable circuitry. In one embodiment, the
6 servo write clock is generated using a phase locked loop (PLL). As each sync mark 10 in the
7 reference servo sectors 34 is detected, the value of the modulo-N counter represents the phase
8 error for adjusting the PLL. Once the modulo-N counter reaches terminal count substantially
9 synchronous with detecting the sync marks 10 in the reference servo sectors 34, the servo write
10 clock is coarsely locked to the desired frequency for writing the product servo sectors to the disk.

11 After synchronizing the servo write clock in response to the reference servo sectors, the
12 spiral tracks 36₀-36_N are read to generate the PES signal for tracking as well as to maintain
13 synchronization of the servo write clock. FIG. 3B illustrates an “eye” pattern in the read signal
14 that is generated when the head 26 passes over a spiral track 36. The read signal representing the
15 spiral track comprises high frequency transitions 38 interrupted by sync marks 40. When the
16 head 26 moves in the radial direction, the eye pattern will shift (left or right) while the sync
17 marks 40 remain fixed. The shift in the eye pattern (detected from the high frequency signal 38)
18 relative to the sync marks 40 provides the off-track information for servoing the head 26.

19 The sync marks 40 in the spiral tracks 36₀-36_N may comprise any suitable pattern, and in
20 one embodiment, a pattern that is substantially shorter than the sync mark 10 in the reference
21 servo sectors 34. Referring again to FIG. 3A, when the sync marks 40 in the spiral tracks 36₀-
22 36_N are detected, the value of the modulo-N counter is compared to an expected value, and the
23 resulting error represents the phase error for adjusting the PLL that generates the servo write
24 clock. In one embodiment, the PLL is updated when any one of the sync marks 40 within the eye
25 pattern is detected. In this manner the multiple sync marks 40 in each eye pattern (each spiral
26 track crossing) provides redundancy so that the PLL is still updated if one or more of the sync
27 marks 40 are missed due to noise in the read signal.

1 In one embodiment, the servo write clock is further synchronized by generating a timing
2 recovery measurement from the high frequency signal 38 between the sync marks 40 in the spiral
3 tracks 36₀-36_N. Synchronizing the servo write clock to the high frequency signal 38 helps
4 maintain proper radial alignment (phase coherency) of the Gray coded track addresses in the
5 product servo sectors. The timing recovery measurement may be generated in any suitable
6 manner. In one embodiment, the servo write clock is used to sample the high frequency signal
7 38 and the signal sample values are processed to generate the timing recovery measurement. The
8 timing recovery measurement adjusts the phase of the servo write clock (PLL) so that the high
9 frequency signal 38 is sampled synchronously. In this manner, the sync marks 40 provide a
10 coarse timing recovery measurement and the high frequency signal 38 provides a fine timing
11 recovery measurement for maintaining synchronization of the servo write clock.

12 FIG. 4 illustrates how the product servo sectors 56₀-56_N are written to the disk 16 after
13 synchronizing the servo write clock using the reference servo sectors 34₀-34_N. In the
14 embodiment of FIG. 4, the dashed lines represent the centerlines of the data tracks. The sync
15 marks in the spiral tracks 36₀-36_N are written so that there is a shift of two sync marks in the eye
16 pattern (FIG. 3B) between data tracks. In an alternative embodiment, the sync marks in the spiral
17 tracks 36₀-36_N are written so that there is a shift of N sync marks in the eye pattern between data
18 tracks. In practice the width of the spiral tracks 36₀-36_N in the embodiment of FIG. 4 will be
19 proximate the width of a data track. The spiral tracks 36₀-36_N are shown in FIG. 4 as being
20 wider than the width of a data track for illustration purposes.

21 The PES for maintaining the head 26 along a servo track (tracking) may be generated
22 from the spiral tracks 36₀-36_N in any suitable manner. In one embodiment, the PES is generated
23 by detecting the eye pattern in FIG. 3B using an envelope detector and detecting a shift in the
24 envelope relative to the sync marks 40. In one embodiment, the envelope is detected by
25 integrating the high frequency signal 38 and detecting a shift in the resulting ramp signal. In an
26 alternative embodiment disclosed below with reference to FIG. 5B, the high frequency signal 38
27 between the sync marks 40 in the spiral tracks are demodulated as servo bursts and the PES

1 generated by comparing the servo bursts in a similar manner as with the servo bursts 14 in the
2 reference servo sectors 34₀-34_N.

3 Once the head 26 is tracking on a servo track, the product servo sectors 56₀-56_N are
4 written to the disk using the servo write clock. Write circuitry is enabled when the modulo-N
5 counter reaches a predetermined value, wherein the servo write clock clocks the write circuitry to
6 write the product servo sector 56 to the disk. The spiral tracks 36₀-36_N on the disk are processed
7 in an interleaved manner to account for the product servo sectors 56₀-56_N overwriting a spiral
8 track. For example, when writing the product servo sectors 56₁ to the disk, spiral track 36₂ is
9 processed initially to generate the PES tracking error and the timing recovery measurement.
10 When the product servo sectors 56₁ begin to overwrite spiral track 36₂, spiral track 36₃ is
11 processed to generate the PES tracking error and the timing recovery measurement.

12 FIGs. 5A-5B illustrate an embodiment of the present invention wherein control circuitry
13 for demodulating the servo bursts in prior art product servo sectors is also used to demodulate the
14 high frequency signal 38 in the spiral tracks as servo bursts to generate the PES for tracking.
15 FIG. 5A shows the eye pattern of FIG. 3B which is processed similar to the prior art product
16 servo sector shown in FIG. 1. The first segment 38A of the high frequency signal in the eye
17 pattern of FIG. 5A is processed as a preamble similar to the preamble 8 in FIG. 1 for
18 synchronizing a read clock 58 generated by a read voltage controlled oscillator (VCO) 60. The
19 first sync mark 40A in the eye pattern is processed similar to the sync mark 10 in FIG. 1. The
20 following segments 38B-38E of the high frequency signal in the eye pattern are demodulated as
21 servo bursts used to generate the PES for tracking.

22 FIG. 5B shows example control circuitry for demodulating the prior art product servo
23 sector of FIG. 1 as well as the eye pattern (FIG. 5A) of the spiral tracks 36. The embodiment
24 employs a read VCO 60 and a write VCO 62. The read VCO 60 generates a read clock 58 for
25 sampling the read signal 64 during normal operation when demodulating the product servo
26 sectors 54 and user data recorded on the disk. The write VCO 62 generates the servo write clock
27 66 used to write the product servo sectors 54 to the disk during the fill operation. The write VCO

1 62 is also used to sample the read signal 64 when demodulating the servo bursts from the high
2 frequency signal 38 in the spiral tracks 36.

3 In one embodiment, the read clock 58 is also used to sample the read signal 64 when
4 reading the first segment 38A of the high frequency signal representing the preamble as well as
5 the first sync mark 40A in the eye pattern (FIG. 5A) of the spiral tracks 36. The read clock 58 is
6 selected by multiplexer 68 as the sampling clock 70 for sampling 72 the read signal 64. The read
7 signal sample values 74 are processed by a first timing recovery circuit 76 which generates a
8 timing recovery signal used to adjust the read VCO 60 until the read clock 58 is sampling the
9 preamble 38A synchronously. Once locked onto the preamble 38A, a sync detector 78 is enabled
10 for detecting the sync mark 40A in the eye pattern. When the sync detector 78 detects the sync
11 mark 40A, it activates a sync detect signal 80. The first timing recovery circuit 76 responds to
12 the sync detect signal 80 by configuring the multiplexer 68 over line 82 to select the servo write
13 clock 66 as the sampling clock 70. The first timing recovery circuit 76 enables a timer for timing
14 an interval between the sync mark 40A and the beginning of the A servo burst 38B in the eye
15 pattern. When the timer expires, the first timing recovery circuit 76 enables a burst demodulator
16 84 over line 86 for demodulating the A, B, C and D servo bursts in the eye pattern from the read
17 signal sample values 74.

18 In one embodiment, the burst demodulator 84 rectifies and integrates the rectified read
19 signal sample values 74 representing the respective A, B, C and D servo bursts to generate
20 respective servo burst signals 88 which correspond to integrating the A, B, C and D servo bursts
21 14 in the prior art product servo sector of FIG. 1. A PES generator 90 processes the servo burst
22 signals 88 to generate a PES signal 92 used for tracking. The PES generator 90 may compare the
23 servo burst signals 88 to generate the PES signal 92 using any suitable algorithm when
24 demodulating the servo bursts in either the prior art product servo sectors of FIG. 1 or the eye
25 pattern of FIG. 5A. In one embodiment, the PES signal 92 when reading the eye pattern of FIG.
26 5A is generated according to $(A-D)/(A+D)$. In this embodiment, evaluating the servo bursts near
27 the edges of the eye pattern increases the sensitivity of the PES measurement. This is because

1 deviations in the radial location of the head 26 cause a more precipitous change in the servo burst
2 values at the edges of the eye pattern as compared to the servo burst values near the center of the
3 eye pattern.

4 In the embodiment of FIG. 5B, a control signal C/S 94 configures the first timing
5 recovery circuit 76, the sync detector 78, and the PES generator 90 depending on whether the
6 control circuitry is configured for demodulating the product servo sector (prior art product servo
7 sector of FIG. 1) or the spiral tracks. The first timing recovery circuit 76 adjusts the timing
8 between the detection of the sync mark (10 in FIG. 1 and 40A in FIG. 5A) and the beginning of
9 the A servo burst (14 in FIG. 1 and 38B in FIG. 5A). The sync detector 78 adjusts the target sync
10 pattern depending on whether the sync mark 10 in the product servo sector is being detected or
11 the sync mark 40A in the eye pattern of the spiral track. The PES generator 90 adjusts the
12 algorithm for comparing the servo burst signals 88 depending on whether the servo bursts 14 in
13 the product servo sectors are being demodulated or the servo bursts 38B-38E in the eye pattern of
14 the spiral track are being demodulated.

15 The control circuitry in the embodiment of FIG. 5B further comprises a second timing
16 recovery circuit 96 for generating a timing recovery measurement that controls the write VCO 62
17 for generating the servo write clock 66. The second timing recovery circuit 96 comprises the
18 modulo-N counter which is synchronized to the sync marks in the reference servo sectors 34 as
19 shown in FIG. 3A. When servoing on the spiral tracks 36, the second timing recovery circuit 96
20 enables a sync mark detection window over line 98 commensurate with the modulo-N counter
21 approaching a value corresponding to the expected occurrence of a sync mark 40 in a spiral track.
22 When a sync mark 40 is actually detected over line 80, the second timing recovery circuit 96
23 generates a coarse timing recovery measurement as the difference between the expected value of
24 the module-N counter and the actual value. When reading the high frequency signal 38 in the
25 spiral tracks, the second timing recovery circuit 96 generates a fine timing recovery measurement
26 using any suitable timing recovery algorithm. For example, the fine timing recovery
27 measurement can be generated using a suitable timing gradient, a suitable trigonometric identity,

1 or a suitable digital signal processing algorithm such as the Discrete Fourier Transform (DFT).
2 The coarse and fine timing recovery measurements are combined and used to adjust the write
3 VCO 62 in order to maintain synchronization of the servo write clock 66.

4 The servo write clock 66 is applied to write circuitry 100 used to write the product servo
5 sectors 56 to the disk during the fill operation. The second timing recovery circuit 96 generates a
6 control signal 102 for enabling the write circuitry 100 at the appropriate time so that the product
7 servo sectors 56 are written at the appropriate circumferential location from the outer diameter of
8 the disk to the inner diameter of the disk. In one embodiment, the control signal 102 enables the
9 write circuitry 100 each time the module-N counter reaches a predetermined value so that the
10 product servo sectors 56 form servo wedges as illustrated in FIG. 1 and FIG. 4.

11 Although the first timing recovery circuit 76 shown in FIG. 5B adjusts the frequency of
12 the read clock 58, any suitable timing recovery technique may be employed. In an alternative
13 embodiment, interpolated timing recovery is employed. With interpolated timing recovery the
14 read signal 64 is sampled asynchronously and interpolated to generate the synchronous sample
15 values 74. In addition, the reference servo sectors 34 may comprise any suitable sync mark
16 recorded at any suitable location within the reference servo sector. In one embodiment, the
17 reference servo sector comprises multiple sync marks to provide redundancy similar to the eye
18 pattern of FIG. 5A.

19 FIGs. 6A and 6B illustrate an embodiment of the present invention for calibrating the
20 correlation between the PES generated from demodulating the spiral tracks 36 and the off-track
21 displacement of the head 26. The segments 38B-38E of the high frequency signal in the spiral
22 tracks 36 are demodulated as servo bursts to generate corresponding servo burst signals A, B, C
23 and D. A PES is generated by comparing the servo burst signals according to any suitable
24 algorithm, such as $(A-D)/(A+D)$. As shown in FIG. 6A, when the head 26 is on track a
25 predetermined relationship between the servo burst signals (e.g., $A=D$) generates a predetermined
26 value for the PES (e.g., zero). The head 26 is then moved away from the center of the track until
27 the servo burst signals reach a second predetermined relationship (e.g., $B=D$) as shown in FIG.

1 6B. When the servo burst signals reach the second predetermined relationship, the shift in the
2 eye pattern relative to the sync marks 40A-40D is known and therefore the amount of off-track
3 displacement is known. Measuring the PES when the servo burst signals reach the second
4 predetermined relationship provides the correlation (assuming a linear relationship) between the
5 PES and the amount of off-track displacement.

6 FIG. 7 shows an embodiment of the present invention wherein after writing the reference
7 servo sectors 34 and spiral tracks 36₀-36_N to the disk 16 (FIG. 2A-2B), the HDA 22 is inserted
8 into an external product servo writer 104 comprising suitable circuitry for reading and processing
9 the reference servo sectors 34 and the spiral tracks 36₀-36_N in order to write the product servo
10 sectors 56₀-56_N to the disk 16. The external product servo writer 104 comprises a read/write
11 channel 106 for interfacing with a preamp 108 in the HDA 22. The preamp 108 amplifies a read
12 signal emanating from the head 26 over line 110 to generate an amplified read signal applied to
13 the read/write channel 106 over line 112. The read/write channel 106 comprises the circuitry of
14 FIG. 5B for generating the servo burst signals 88 applied to a servo controller 114. The servo
15 controller 114 processes the servo burst signals 88 to generate the PES 92. The PES 92 is
16 processed to generate a VCM control signal applied to the VCM 28 over line 116 in order to
17 maintain the head 26 along a circular path while writing the product servo sectors 56₀-56_N. The
18 servo controller 114 also generates a spindle motor control signal applied to a spindle motor 118
19 over line 120 to maintain the disk 16 at a desired angular velocity. Control circuitry 122
20 processes information received from the read/write channel 106 over line 124 associated with the
21 spiral tracks (e.g., timing information) and provides the product servo sector data to the
22 read/write channel 106 at the appropriate time. The product servo sector data is provided to the
23 preamp 108 which modulates a current in the head 26 in order to write the product servo sectors
24 56₀-56_N to the disk 16. The control circuitry 122 also transmits control information over line 126
25 to the servo controller 114 such as the target servo track to be written. After writing the product
26 servo sectors 56₀-56_N to the disk 16, the HDA 22 is removed from the external product servo

1 writer 104 and a printed circuit board assembly (PCBA) comprising the control circuitry 20 (FIG.
2 2A) is mounted to the HDA 22.

3 In one embodiment, the external product servo writer 104 of FIG. 7 interfaces with the
4 HDA 22 over the same connections as the control circuitry 20 to minimize the modifications
5 needed to facilitate the external product servo writer 104. The external product servo writer 104
6 is less expensive than a conventional servo writer because it does not require a clean room or
7 sophisticated head positioning mechanics. In an embodiment shown in FIG. 8, a plurality of
8 external product servo writers 104₀-104_N process the HDAs 22_{i-i+N} output by an external spiral
9 servo writer 32 in order to write the product servo sectors less expensively and more efficiently
10 than a conventional servo writer. In an alternative embodiment shown in FIG. 9, an external
11 spiral servo writer 32 is used to write the reference servo sectors and the spiral tracks, and the
12 control circuitry 20 within each product disk drive 18₀-18_N is used to write the product servo
13 sectors.